AGRO 2015 MONTPELLIER
07 -10 SEPTEMBER

The International Scientific Week on Agricultural Systems

FSD5 Proceedings

FSD Agricultural systems by design

SEPTEMBER 7-10, 2015

Le Corum
MONTPELLIER
France

5th International Symposium for Farming Systems Design

"Multi-functional **farming systems** in a **changing world**"

ESA European Society for Agronomy

AGROPOLIS INTERNATIONAL

Proceedings of the 5th International Symposium for Farming Systems Design

FSD5

Montpellier, September 7 - 10, 2015

Editors: Gritti Emmanuel S. – Wery Jacques
Cover design: Olivier Piau – Lisbeth Michel
Final edition: Gritti Emmanuel S.

Special thanks to the scientific committee's members for their commitment in the reviewing and editing processes

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Design of innovative orchards: proposal of an adapted conceptual framework

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1 Introduction

System experiments are a developing approach to address complex questions such as the design and management of sustainable cropping systems. If the general framework of system experiments is well documented and adapted to iteratively design annual cropping systems (Debaeke *et al*., 2009), specificities of other crops are not always considered with possible limits at using the approach. As perennial and multi-layer systems that produce fresh fruit, orchards are complex agroecosystems that require specific design and management over space and time. The present work analyzed two contrasted system experiments aiming at decreasing pesticide use in temperate (apple) and Mediterranean/tropical (citrus) fruit productions. Our aim was to examine similarities and differences, and to propose a conceptual framework for designing innovative orchards.

2 Materials and methods

A crossed analysis was used to identify general aims, methodology used to design, type of levers combined to decrease pesticide use and related processes, and nature of outputs of the two studied system experiments (Table 1, Fig. 1).

Table 1. Main outlines of the two studied experiment systems.

	Apple (Simon *et al*., 2011)	**Citrus** (Le Bellec *et al*., 2012)
Research program	BioREco	ECOFRUT followed by Agrum'Aide
Location	South-East France	Reunion Island (France)
Orchard type	System experiment	Growers'orchard network
Study period	2005-2015	2010-2018
General aim / target pests	Pesticide use decrease / insects, diseases, weeds	Pesticide use decrease / insects and weeds
Methodology to design orchards	Mix of prototyping & step by step approach based on scientific knowledge and experience	tory approach involving growers, advisors, scientists; Step by step approach
Main levers used to decrease pesticide use (see also Fig. 1)	Low-susceptibility cultivar & combining of several methods	Weeds management with or without introduction of cover crop
Main processes at stake and practices to control pests	Bottom-up and top-down processes & direct measures	Bottom-up and top-down processes & direct measures
Main outputs	Important pesticide decrease(45-60%) when all levers are combined& information of damage risk available	Important pesticide decrease (50 % and more) when the growers are implicated as co-designers of the cropping system http://cosaq.cirad.fr/projets/agrum-aide

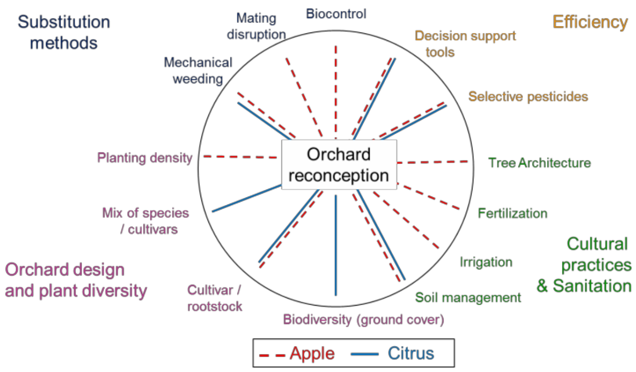

Fig. 1. Main levers combined to (re-)design apple and citrus orchard systems to manage orchard pests. Levers refer to broad non-exclusive groups of levers according to their nature and/or mode of action; Orchard reconception combines all types of levers.

3 Results – Discussion: Spatial and temporal design of innovative orchards towards more sustainability

This cross-analysis outlined (Table 2) three main aspects:
-The young unproductive stage of the orchard that can last for 2 to 5 years according to fruit species and cultivar requires careful management as the development and yield of the adult tree is building up during this stage.
-The permanency of the crop constrains the management of soil fertility: some practices are no more possible (e.g. legume crops in the rotation), fertilizing and ground cover management differentiate between tree rows and alleys.
-The longevity of the crop constrains decision making: a pest can be damageable in the present but also in the following seasons as many serious pests can complete their lifecycle in the orchard and build up important populations or inoculum across years. This is especially true in tropical areas where there is no dormant season. Conversely, the permanency of the orchard habitats facilitates the planting or sowing of plant assemblages (e.g., ground covers, lining hedgerows) to enhance conservation biocontrol and/or compete weeds, provided non-disruptive practices are applied.

Table 2. Specificities of the design and management of orchard systems compared to rotational systems.

	Rotational cropping systems	**Orchard systems**
Cropping system design	One-layer annual crops, no woody crop	Tree rows;arboreal and herbaceous layers; conservative design, i.e.treedensity, cultivar
Cropping system lifetime	Seasonal crops in the rotation with some exceptions (e.g. alfalfa)	Pluriannual young stage constrains the orchard potential yield
Fertilization and soil management	Whole-field fertilizer supply	Alley/tree row differentiation for fertilization; no tillage/ploughing in the alley
Soil cover and crop management	Successive crops	Permanent ground cover in the alleys and sometimes in the tree row; permanent trees with complex architecture
Weed management	Long-term decisional management	Long-term decisional management
Pest and disease management	Pest/disease lifecycle broken by crop sequences	Possible increase in population/inoculum across years; pest damage can affect yield in the following years (e.g. aphids affect growth)
Natural enemies management	Scarce permanent resources and habitat unless semi-natural habitats are present	Management of within-, peri- and extra-orchard permanent resources and habitats

4Conclusions

Because of their longevity, orchards permit to foster both bottom-up and top-down processes in the food chain. Therefore, they offer opportunities to redesign the cropping system within space and time (Fig. 2), and to enhance ecosystem services such as pest and weed control through the management of cultivated and companion plants (Thies *et al.*, 2003; Tscharntke *et al.*, 2007). In such perennial cropping systems requiring intensive and long-term management, interactions among the orchard life stages, spatial and functional dimensions and practices need to be explicitly considered to optimize the efficiency of the system as a whole. Such complexity in the re-design requires knowledge from many stakeholders in the food system (growers, advisors, scientists…). Co-design also requires more and renewed interactions among these stakeholders with the aim of building capacity in participatory approach appropriation, and for growers in the design of their own orchard and decisional system (Le Bellec *et al.*, 2012; Lauri, 2014).

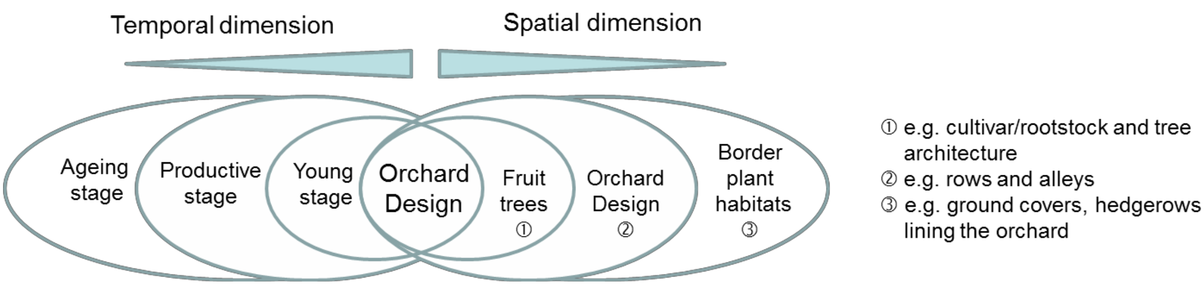

Fig. 2. General framework: main dimensions to consider when designing orchard systems.

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